DEMONSTRATION OF OXIDANT-ENHANCED LIME-BASED SORBENTS

BENCH-SCALE CONFIRMATION OF SORBENT INTERACTIONS AND APPLICATIONS

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Demonstration of Oxidant-Enhanced Lime-Based Sorbent

Bench-Scale Confirmation of Sorbent Interactions and Applications

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Introduction

ARCADIS, working with the U.S. Environmental Protection Agency (EPA), has developed lime-based sorbents for mercury application as part of a multi-pollutant control strategy. Oxidant has been incorporated into the prospective sorbents to enhance the oxidation of elemental mercury and subsequent capture on a basic substrate. Bench-scale evaluations of the sorbent indicated mercury removal was dependent on SO_2 concentration. These promising sorbents, however, had not been evaluated under actual flue gas conditions that would be encountered at coal-fired plants. Principal components missing in these evaluations included nitric oxide, carbon monoxide, and ash.

Southern Research Institute (SRI) has been awarded a contract by the Department of Energy (DOE) to evaluate lime-based sorbents on their pilot combustor. ARCADIS teamed with SRI on this project to provide oxidant-enhanced lime-based sorbent for demonstration. Two sorbents were provided: one based on hydrated lime and one silica-lime sorbent. During pilot-scale testing of these sorbents, an increase in elemental mercury (Hg^0) concentration while injecting sorbent was observed at the baghouse outlet relative to baseline operation. In addition, the total amount of mercury removal was only 25 percent with hydrated lime sorbent and 50 percent with silica-lime sorbent. SRI expressed interest in further bench-evaluation of these sorbents prior to continued pilot tests.

ARCADIS implemented a test program to resolve some of the remaining questions with respect to these sorbents. The primary question to resolve is whether a sorbent /fly ash interaction exists that results in an increase in Hg^0 concentration. In addition, this plan attempts to answer whether oxidized mercury is somehow reduced to Hg^0 by the action of the sorbent. Finally, interactions of the sorbent, with other flue gas components, are investigated to determine if they prevent the oxidation and control of Hg^0.

Methods and Materials

A bench-scale test stand was constructed at EPA's research facilities in Research Triangle Park, North Carolina. Sorbent is exposed to simulated flue gas in a glass fixed-bed reactor. The reactor is situated within a gravity oven, which controls reaction temperature using a PID controller. A bypass loop is installed outside the oven using 3-way Teflon valves.

Gaseous Hg^0 is generated by passing nitrogen at 100 cc/minute through a permeation oven containing Hg^0 permeation tubes. Two permeation tubes with a certification temperature of 100 ºC were used to generate 504 ng Hg^0 vapor per minute. Both temperature and flow were maintained constant through the permeation oven, but the flow was shunted to exhaust when not being used.

Simulated flue gas is generated from tanks using six mass flow controllers (MFC). One MFC continuously purges the permeation oven at the rate of 100 cc/minute. A second MFC provides the necessary makeup nitrogen to provide desired flow. One MFC connected to an air tank to provide oxygen and to a nitrogen tank to provide makeup nitrogen for standardization; the gas supply source is controlled by toggle valves. One MFC connects to a low-pressure CO_2 tank. SO_2 in air span gas is controlled by an MFC to produce the appropriate SO_2 concentration. The final MFC controls NO and CO span gas in nitrogen. All MFCs were calibrated prior to this test series with air, nitrogen, or CO_2 as appropriate to the specific MFC application.

Water vapor is generated by pumping water into a heated steel vessel maintained at 120-130 ºC during testing. The vessel is heated by resistance heat tape and is insulated to minimize cold spots. Water is pumped into the vessel with a peristaltic pump. Rate of water addition is monitored gravimetrically. Evaporated water diffuses into the Hg^0 laden gas mixture. The mixture does not pass through the evaporation vessel.

Exhaust from the reactor or bypass loop is dried using a Permapure drier prior to analysis. House air is passed through a dessicant and fed to the shell side of the Permapure drier. The entire flow path from the Hg^0 generator to the Permapure drier is heat traced and insulated to prevent condensation.

Exhaust from the Permapure drier is available for analysis. A slipstream of this exhaust is extracted and analyzed for NO_X with a chemi-luminescent analyzer. A separate slipstream is extracted and analyzed for SO_2 by UV absorption and for Hg^0 by UV absorption. The mercury analyzer detects Hg^0 and has a response to both SO_2 and water. Water is eliminated with the Permapure drier. Hg^0 response to SO_2 is subtracted from the apparent Hg^0 concentration. Output from the analyzers was logged on a computer acquisition system on a 10 second polling interval.

Each test was bracketed by a nitrogen baseline, a Hg^0 in nitrogen baseline, and a simulated flue gas baseline. These baselines were used to standardize the analyzer outputs. Baseline responses before and after the test were averaged to average out zero and span drift on the analyzer.

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The test program was intended to simulate conditions encountered during pilot evaluation of the oxidant-enhanced lime sorbent at SRI. The simulated flue gas generally contained 9 percent volume oxygen, 16 percent volume CO_2, 730 ppmv SO_2, 300 ppmv NO, 115 ppmv CO, and 252 µg/scm Hg^0 on a dry basis. Water was evaporated to achieve 7.8 percent volume water vapor. Concentrations of SO_2, NO, and CO were changed by reducing or eliminating flow. Effects of NO and CO were segregated by switching cylinders between NO and CO in nitrogen, NO in nitrogen, and CO in nitrogen. During each test total flow through the system was maintained at 2 L/minute for one hour. Tests were either conducted at 80 ºC to simulate conditions on the pilot during sorbent injection or at 140 ºC to simulated conditions on the pilot prior to and after sorbent injection.

The test program evaluated ash and sorbent representative of the pilot tests. Ash was obtained from SRI baghouse catch. A small batch of sorbent was hydrated to simulate sorbent evaluated on the pilot using commercial powdered quicklime and reagent oxidant. Tests were performed with 0.71 g ash and/or 0.40 g of sorbent mixed with glass beads as a dispersant. These proportions reflect the estimated composition of the baghouse catch during pilot sorbent tests.

Results and Discussion

Analysis of the test results was performed by segregating the tests into saturated factorial matrixes. This approach results in a 2^3 matrix varying ash, sorbent, and exposure temperature with a comprehensive simulated flue gas, a 2^2 matrix varying NO and CO concentration together and varying exposure temperature with sorbent but without fly ash, and a 2^2 matrix varying NO and CO concentration independently. Each matrix was then analyzed independently for each pollutant. A summary of the test results is presented in Table 1.

The Hg^0 response of these bench tests reflects both sorption and oxidation of Hg^0 only. The analyzer used does not respond to oxidized forms of mercury. The primary concern of this bench test program was the oxidation of Hg^0 due to the nature of the sorbent and the interferences of concern. Therefore, no conversion of oxidized mercury was attempted. Oxidized mercury may either be captured or emitted without detection with the current test stand configuration.

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Table 1: Summary of Test Responses

Conditions	NO_X Response, mg NO removed	SO_2 Response, mg SO_2 removed	Hg^0 Response, µg Hg^0 removed
blank, 80 °C	0.45	4.98	0.33
ash, 80 °C	0.06	5.70	1.56
sorbent, 80 °C	2.39	36.43	2.19
ash & sorbent, 80 °C	2.33	36.06	3.69
_____	2.25	34.90	4.12
average	2.29	35.48	3.91
blank, 140 °C	0.45	8.18	1.03
ash, 140 °C	0.30	7.48	8.96
sorbent, 140 °C	1.65	38.95	6.52
ash & sorbent, 140 °C	2.22	47.24	9.47
_____	1.96	38.39	10.08
average	2.09	42.82	9.78
sorbent, 80 °C 0 ppm NO, 0 ppm CO	NA	48.17	11.24
sorbent, 140 °C 0 ppm NO, 0 ppm CO	NA	37.02	22.17
sorbent, 80 °C 0 ppm NO	NA	48.86	11.99
sorbent, 80 °C 0 ppm CO	2.01	36.61	3.96

While a replicate half-fraction of the 2^3 matrix was planned, only two acceptable replicates were obtained. These two replicates provide the basis for error estimates. The 2^3 factorials were analyzed using the method of unweighted means; analysis was performed on the average response and Mean Square Error was adjusted for the use of means. The 2^2 factorials contain no replication requiring an approximation of variance as the Mean Square Error of the aforementioned replicate tests.

Sorbent Response to NO/CO and Temperature

While no analysis is available for CO, it seems that the sorbent has some activity toward NO at test conditions. Based on the replicate tests, a 95 percent prediction interval at these conditions is ±0.59 mg NO removal. No NO_X removal estimates are applicable to the tests performed without NO and CO, however, runs with NO and CO produced responses of 2.39 and 1.65 mg NO removal at low and high reaction temperatures. While the difference between low temperature and high temperature NO_X response is not significant at 95 percent confidence, each is significantly higher than zero.

SO_2 removal was consistent over these four tests. Table 2 indicates that neither presence of NO and CO nor change in temperature effected SO_2 removal. The 95 percent prediction interval based on the replicate tests is ±19.2 mg SO_2 with 2 degrees of freedom. The average response of this matrix was 40.1 mg SO_2 removed. Reducing temperature is typically associated with an increase in SO_2 removal with lime-based sorbents as the temperature approaches the adiabatic saturation temperature. The lack of SO_2 response to temperature is likely due to the small water adsorption typical of these operating conditions; 17 percent relative humidity at 80 ºC and 2.2 percent relative humidity at 140 ºC.

Hg^0 removal was quite varied over these four tests. Using the replicate tests, the 95 percent prediction interval at these conditions is ±1.60 µg Hg. These four tests ranged from 2.19 µg Hg^0 to 22.2 µg Hg^0. The ANOVA presented in Table 3 indicates that both the presence of NO and CO and the change in reaction temperature and the interaction of these two factors are significant at the 95 percent confidence level. Though convention suggests Hg^0 removal is improved by decreasing temperature, these results clearly show that reduction in Hg^0 improves significantly at higher temperatures,

Table 2: SO₂ ANOVA for NO/CO and Temperature

	SS	DF	MS	F	p-value
A:NO/CO	24.06	1	24.06	1.21	0.386
B: Temperature	18.62	1	18.62	0.93	0.436
AB	46.72	1	46.72	2.35	0.265
Error		2	19.92		

SS = sum of squares

DF = degrees of freedom

MS = mean square

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Table 3: Hg^0 ANOVA for NO/CO and Temperature

	SS	DF	MS	F	p-value
A: NO/CO	152.52	1	152.52	1095.31	0.001
B: Temperature	58.22	1	58.22	418.07	0.002
AB	10.89	1	10.89	78.20	0.013
Error		2	0.14		

nearly doubling Hg^0 removal when increasing from 80 to 140 ºC without NO and CO. This sorbent is oxidizing Hg^0 and the reaction appears to be enhanced by elevated temperatures. This result negates concerns over thermal decomposition since the sorbent in the test stand is brought to reaction temperature prior to introduction of simulated flue gas. Though Hg^0 is believed to be in competition with SO_2 for oxidant, the constant removal of SO_2 at these test conditions confounds analysis of this effect. There remains considerable concern, however, regarding competition for oxidant by NO and/or CO. Previous bench-scale development was not performed in the presence of NO or CO. Presence of NO and CO do have a significant impact on Hg^0 removal. At 80 ºC, presence of NO and CO reduced Hg^0 removal by 81 percent. At 140 ºC, presence of NO and CO reduced Hg^0 removal by 71 percent. High temperatures again tend to favor Hg^0 removal over NO or CO removal.

Sorbent Response to NO and CO at 80 ºC

After discovering the dramatic effect of NO and CO on Hg^0 removal, follow up tests were performed to determine which species was responsible. A single test with sorbent at 80 ºC was performed with simulated flue gas without NO and a single test was performed with simulated flue gas without CO. These tests are evaluated with aforementioned tests however interaction between NO and CO are confounded with a potential block effect; the tests were performed with significant intervening time and intervening experiments.

Removal of CO from the simulated flue gas at 80 ºC resulted in a NO_X response of 2.01 mg NO. Response with both NO and CO at 80 ºC was 2.39 mg NO while the 95 percent prediction interval is ±0.59 mg NO. When discounting the potential block effect, NO_X response with CO is indistinguishable from the response without CO.

Removal of CO from the simulated flue gas at 80 ºC resulted in a SO_2 response of 36.61 mg SO_2 removed. Removal of NO from the simulated flue gas at 80 ºC resulted

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in an SO_2 response of 48.86 mg SO_2 removed. Based on the ±19.2 mg SO_2 prediction interval, these responses are not significantly different at the 95 percent confidence level. Combining these results with the 80 ºC no NO/no CO test and with the 300 ppm NO/115 ppm CO test results in no significant effect toward SO_2 at the 95 percent confidence level. The SO_2 ANOVA for these four tests is shown in Table 4.

Removal of CO from the simulated flue gas at 80 ºC resulted in a Hg^0 response of 3.96 µg Hg^0. Removal of NO from the simulated flue gas at 80 ºC resulted in an Hg^0 response of 11.99 µg Hg^0. Combining these results with the 80 ºC no NO/no CO test and with the 300 ppm NO/115 ppm CO test results in a significant effect associated with NO and no significant effect associated with CO or experimental blocking at the 95 percent confidence level. The Hg^0 response ANOVA for these tests is shown in Table 5. NO at 300 ppm appears to be responsible for a reduction in Hg^0 response by an average of 8.54 µg or 74 percent at 80 ºC. NO appears to be competing with Hg^0 for the oxidant on the sorbent. Sorbent performance toward Hg^0 will clearly be improved by any systematic changes resulting in lower NO_X emissions. A number of conditions in the coal-fired utility population result in a significantly reduced level of NO_X than evaluated on the pilot tests including: firing configurations (such as tangential firing), burner design, and fuel properties. Additional post-combustion controls for NO_X, such as SCR or reburning, are feasible and warranted under current and proposed regulatory considerations. While not required for effective Hg^0 control, low NO_X emissions will contribute to cost effective mercury control with oxidant-enhanced lime-based sorbents.

Response to Ash, Sorbent and Temperature

A small but significant NO_X removal was observed in these experiments. The ANOVA for these experiments, shown in Table 6, indicates that only the presence of sorbent resulted in a significant response at the 95 percent confidence level. Average NO_X response for experiments without sorbent was 0.32 mg NO removal while average NO_X response for experiments with sorbent was 2.11 mg NO removal. NO_X removal is approximately 5 percent at these conditions. The fly ash does not appear to contribute to nor detract from NO_X removal. Reaction temperature also does not appear to affect the NO_X response.

Table 4: SO_2 ANOVA for NO and CO at 80 ºC

	SS	DF	MS	F	p-value
A: NO	143.88	1	143.88	7.22	0.115
B: CO	0.07	1	0.07	0.00	0.960
AB+Block	0.19	1	0.19	0.01	0.931
Error		2	19.92		

Table 5: Hg^0 ANOVA for NO and CO at 80 ºC

	SS	DF	MS	F	p-value
A: NO	72.93	1	72.93	523.75	0.002
B: CO	0.26	1	0.26	1.87	0.305
AB+Block	1.59	1	1.59	11.40	0.078
Error		2	0.14		

Table 6: NO_x ANOVA for Ash, Sorbent and Temperature

	SS	DF	MS	F	p-value
A: Ash	0.01	1	0.01	0.31	0.634
B: Sorbent	6.41	1	6.41	395.87	0.003
C: Temperature	0.06	1	0.06	3.78	0.191
AB	0.10	1	0.10	5.98	0.134
AC	0.08	1	0.08	4.70	0.163
BC	0.17	1	0.17	10.75	0.082
ABC	0.01	1	0.01	0.69	0.492
Error		2	0.02		

Significant SO_2 removal was also observed in these experiments. The ANOVA for these experiments, shown in Table 7, indicates that sorbent was again the only significant factor in SO_2 response at the 95 percent confidence level. Average SO_2 removal for experiments without sorbent was 6.59 mg SO_2 removed while average response with sorbent was 38.4 mg SO_2 removed. The fly ash does not appear to contribute to nor detract from SO_2 removal. Reaction temperature also does not appear to affect the SO_2 response.

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Table 7: SO$_2$ ANOVA for Ash, Sorbent and Temperature

	SS	DF	MS	F	p-value
A: Ash	1.08	1	1.08	0.06	0.827
B: Sorbent	2026.78	1	2026.78	116.30	0.009
C: Temperature	27.51	1	27.51	1.58	0.336
AB	1.05	1	1.05	0.06	0.829
AC	1.44	1	1.44	0.08	0.801
BC	2.97	1	2.97	0.17	0.720
ABC	4.86	1	4.86	0.28	0.650
		2	17.43		

The combination of the three factors: ash, sorbent, and temperature, produced a complex Hg^0 response. The Hg^0 response ANOVA for these experiments, shown in Table 8 indicates that ash, sorbent, and temperature all produced significant effects at 95 percent confidence level along with significant interaction effects. The three factor interaction suggests that ash and sorbent interact differently at the two reaction temperatures evaluated. In interpreting these results as they relate to SRI pilot tests, it is convenient to examine the tests without sorbent and tests with sorbent separately.

Table 8: Hg^0 ANOVA for Ash, Sorbent and Temperature

	SS	DF	MS	F	p-value
A: Ash	24.96	1	24.96	204.83	0.005
B: Sorbent	13.81	1	13.81	113.32	0.009
C: Temperature	41.86	1	41.86	343.57	0.003
AB	2.19	1	2.19	18.01	0.051
AC	8.49	1	8.49	69.66	0.014
BC	0.55	1	0.55	4.52	0.167
ABC	3.33	1	3.33	27.32	0.035
Error		2	0.12		

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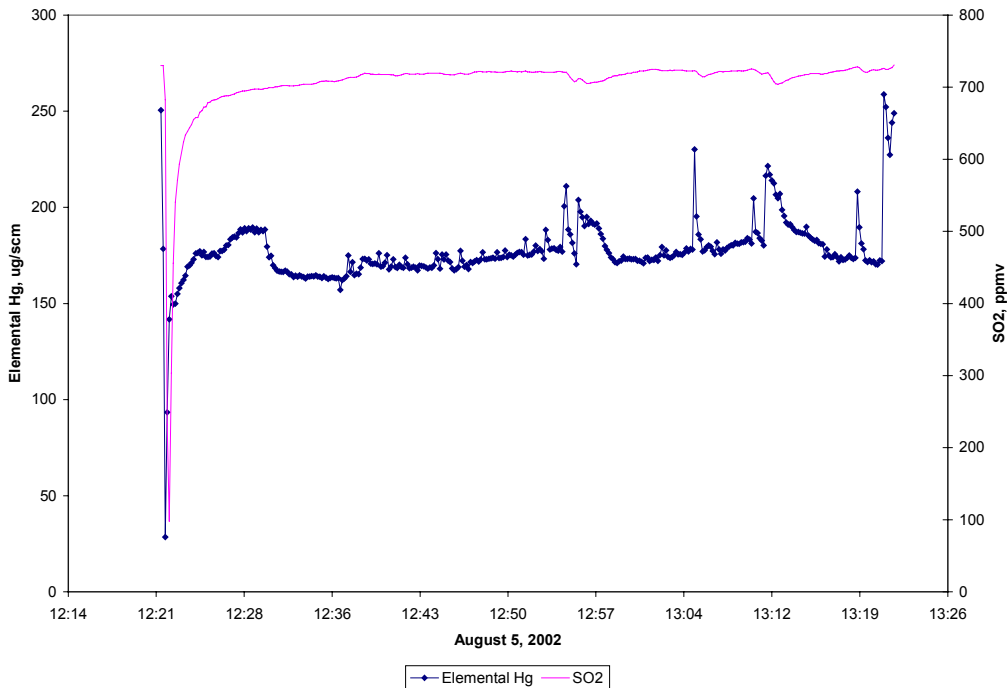Hg^0 Response of Ash to Temperature

When tests were performed with neither sorbent nor ash in the reactor, a minor response was observed which could be interpreted as the bias in the test stand. This bias is largely related to the dead volume in the reactor prior to initiating the test but also includes adsorption wall effects. These blank tests resulted in 0.33 and 1.03 µg Hg^0 removed at 80 ºC and 140 ºC respectively. Recalling that the prediction interval for Hg^0 response was 1.60 µg Hg^0, these responses are indistinguishable from each other.

Tests with ash included in the reactor were not indistinguishable. Ash exposed at 80 ºC produced a response of 1.56 µg Hg^0 removed while ash exposed at 140 ºC produced a response of 8.96 µg Hg^0 removed. Any removal by the ash at 80 ºC is quite small; suggesting that at the low temperatures encountered during pilot sorbent tests, no appreciable adsorption or oxidation of Hg^0 is expected by the ash. As shown in Figure 1, the Hg^0 removal was significant relative to 252 µg/scm baseline value at 140 ºC. Though the Hg^0 breakthough curve with ash was somewhat erratic, there was no consistent decline in Hg^0 removal over the course of the tests; suggesting a diffusion limitation and/or a catalytic reaction. These results are consistent with a catalytic oxidation on the ash with subsequent desorption of oxidized mercury species. Oxidation and desorption are consistent with the high level of oxidized mercury encountered in the pilot tests prior to sorbent injection and concomitant cooling of the flue gas. This phenomenon is reasonably established as a source of speciation bias in Ontario - Hydro sampling with hot filters.

The simulated flue gas is of particular interest with respect to these results. The gas contains oxygen, carbon dioxide, sulfur dioxide, nitric oxide, carbon monoxide, and water at levels representative of the pilot plant. Apparent oxidation of Hg^0 occurred in these tests despite the presence of other pollutants available to occupy active sites. In addition, no chlorine species were included in the simulated flue gas, which suggests the only potential role for chlorine in removal by fly ash is in the creation of active sites.

Hg^0 Response of Sorbent and Ash at 80 ºC

The pilot tests added sorbent to flue gas containing fly ash while controlling the baghouse temperature to nominally 80 ºC. As previously discussed, these bench tests indicate that ash alone at 80 ºC removed a small amount, 1.56 µg, of Hg^0. Adding sorbent to the fly ash at 80 ºC resulted in an increase in Hg^0 removal to 3.91 µg Hg^0. The test

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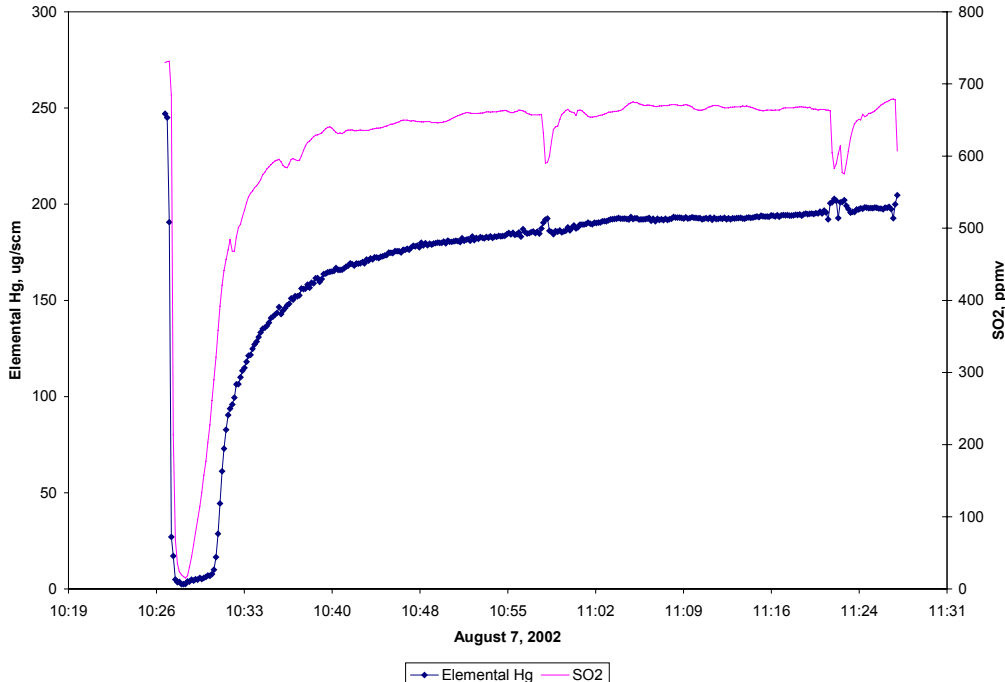Applications

Figure 1: Breakthrough Profile with Ash at 140 ºC

with only sorbent resulted in a reduction to 2.19 µg Hg. These responses indicate an average ash response of 1.48 µg Hg^0 removal while sorbent contributed 2.11 µg Hg^0 removal. The effect of adding fly ash at 80 ºC is not statistically significant at 95 percent confidence level. There is no statistically significant interaction of ash and sorbent at 80 ºC. These results indicate that pilot tests with sorbent did not benefit significantly by Hg^0 removal or Hg^0 oxidation associated with the ash dispite significant Hg^0 removal, attributed to oxidation, associated with the ash at higher temperatures prior to sorbent injection and gas cooling.

Hg^0 Response of Ash and Sorbent at 140 ºC

The bench test with ash alone at 140 ºC resulted in 8.96 µg Hg^0 removed. Adding sorbent to ash resulted in a modest increase to an average 9.78 µg Hg^0 removed at 140 ºC. Removing the ash and testing sorbent alone resulted in 6.52 µg Hg^0 removed.

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At 140 ºC, ash, sorbent and the interaction of the two produce significant effects at the
95 percent confidence level. The breakthrough profile of a test with ash and sorbent at
140 ºC is shown in Figure 2. The profile appears to combine a constant removal, such
as associated with the ash alone, with a consumptive component dominating in the first
10 minutes of exposure. The net effect of adding sorbent to ash at 140 ºC is to increase
the Hg^0 removed, however, this increase is less than the additive effects of ash and
sorbent alone. These effects would only have been encountered in the pilot tests during
excursions from steady-state such as at the beginning of sorbent injection prior to
cooling the baghouse or after sorbent injection and cessation of water injection.

Several mechanisms may help explain the interaction of ash and sorbent at high
temperatures. While it is conceivable that a reaction product from the sorbent fouls
sites on the ash, the continued removal of Hg^0 at extended reaction times suggests this
is unlikely to have significantly degraded ash activity. Reaction product from the
sorbent may however interact with non-active sites on ash to a significant degree and

Figure 2. Breakthrough Profile with Ash and Sorbent at 140 ºC

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thus become unavailable for Hg^0 removal. Similarly, it may be postulated that a reaction product from the ash, such as mercuric oxide or perhaps SO_3, could foul sites on the sorbent. This mechanism may function by occlusion if a result of oxidized species or by consumption of oxidant if reduced species such as semi-volatile organics were involved.

Though transfer of species is a possible mechanism for the ash sorbent interaction, depletion of Hg^0 accounts for some of the interaction. Hg^0 that is oxidized by the sorbent is not available for the ash to catalyze. Similarly, Hg^0 that is oxidized by the ash is not available for the sorbent to remove. Since Hg^0 is in competition with other gas components such as SO_2 and NO for oxidant, delayed consumption of oxidant by Hg^0 will reduce the Hg^0 oxidation potential.

While further study of this interaction may be useful for future process development, it is secondary to the observation that temperatures close to typical air heater outlet temperatures result in significantly more removal of Hg^0. No deterioration in the sorbent resulted at these temperatures. Additionally, no net chemical reduction of oxidized mercury to Hg^0 was observed when ash and sorbent were mixed.

Conclusions & Recommendations

Calcium-based oxidant enhanced sorbent was evaluated in a bench-scale reactor using simulated flue gas designed to mimic pilot operations and was found to be active toward Hg^0. Sorbent was found to be significantly more active toward

Hg^0 at high temperatures (140 ºC) typical of air heater outlet temperatures. Further, bench tests indicated no effect of increasing reaction temperature from 80 to 140 ºC on SO_2 removal. Future pilot investigations should evaluate the ability of the sorbent to capture mercury with no or lower flue gas cooling.

Ash from the SRI pilot was found to have insignificant activity toward Hg^0 at 80 ºC but substantial activity toward Hg^0 at 140 ºC. Ash is proposed to catalyze Hg^0 oxidation by flue gas components at 140 ºC. Ash with sorbent resulted in no net increase in Hg^0 at constant reaction temperatures.

These tests have demonstrated that pollutants in the flue gas compete for oxidant on the calcium-based oxidant enhanced sorbent. Specifically, NO was found to have a great impact on the oxidation of Hg^0. CO was found to have no significant impact on the oxidation of Hg^0. It is clear that the sorbent will be more effective in environments that

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have low concentrations of competing species such as NO and SO_2. Therefore, it is recommended that future pilot operations evaluate the sorbent under conditions which result in significant control of NO and/or SO_2.

In Summary, further SRI pilot evaluation of oxidant-enhanced lime-based sorbents are recommended. Future pilot test programs should further define the operating conditions at which the sorbent will be effective toward Hg^0 and total mercury. Factors to be considered in this program should include reaction temperature, NO_X concentration, and SO_2 concentration. Reaction temperature may be controlled on the pilot by the amount of water added to the system. NO_X concentration may be controlled on the pilot by conventional means including SCR, SNCR, and reburning. SO_2 concentration may be controlled by either implementing sorbent recycle or adjusting sorbent stoichiometry. Control of these factors at full-scale implementations will depend on site-specific considerations including equipment configuration, operating parameters and fuel source. The pilot evaluations will be instrumental in defining the most effective applications of this technology.